NPDGamma Polarized ^{3}He Spin Filter Technical Note

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November 1st, 2000

Polarized ^{3}He can be used as a spin filter for the NPDGamma experiment because of the large difference in the absorption cross section for the two spin states. Neutron capture for neutrons polarized in the same direction as the ^{3}He is essentially disallowed by the Pauli exclusion principle. As a result, neutrons whose spin is anti-aligned with the ^{3}He are captured in the polarized ^{3}He cell (filtered out), while neutrons whose spin is aligned with the ^{3}He pass through the cell. The capture cross section is $\sigma_a = (v_0/v)\,\sigma_0$ where $\sigma_0 = 5327$b at $v_0 = 2200$ m/s. The neutron polarization and transmission from the ^{3}He cell are:

$$T_+ = e^{-n_3\sigma_a l\,(1-P_3)} \tag{1}$$

$$T_- = e^{-n_3\sigma_a l\,(1+P_3)} \tag{2}$$

$$P_n = \frac{T_+ - T_-}{T_+ + T_-} = \tanh\left(n_3\sigma_a l P_3\right) \tag{3}$$

$$T_n = \frac{T_+ + T_-}{2} = e^{-n_3\sigma_a l}\cosh\left(n_3\sigma_a l P_3\right) \tag{4}$$

where n_3 is the ^{3}He number density, l is the length of the spin filter, and P_3 is the ^{3}He polarization. To put in some numbers,

1 barn $= 1 \times 10^{-24}$ cm^2
1 amagat $= 2.6868 \times 10^{19}$ cm^{-3}
$v = 437.4$ m/s at 1 meV

Expressing the density times the thickness of the ^{3}He cell, $(n_3 l = A)$, in units of amagat cm, and the neutron energy in units of meV, the neutron polarization and transmission are:

$$P_n = \tanh\left(\frac{0.72AP_3}{\sqrt{E}}\right) \tag{5}$$

$$T_n = e^{-\left(0.72A/\sqrt{E}\right)}\cosh\left(\frac{0.72AP_3}{\sqrt{E}}\right) \tag{6}$$

To get the polarization and transmission as a function of time of flight (tof), we need to know the length of the flight path, L. Expressing the length, L, in meters and (tof) in ms, we have:

$$\frac{1}{\sqrt{E}} = \frac{437.4(tof)}{1000L} \tag{7}$$

$$P_n = \tanh\left(\frac{0.315AP_3(tof)}{L}\right) \tag{8}$$

$$T_n = e^{-\,(0.315A(tof)/L)} \cosh\left(\frac{0.315AP_3(tof)}{L}\right) \tag{9}$$

The length of the flight path for the NPDGamma test run 2000 was 21.9 m with an error of approximately 0.5 m. This number will be improved once the Bragg edge data has been analyzed.

The value of AP_3 was measured and monitored by the ^{3}He NMR system. The NMR signal peak height, S_3, is proportional to the magnetization, which is proportional to the product of the density times the thickness times the polarization, which is AP_3. Since at a given L, the product of AP_3 determines the neutron polarization as a function of (tof), a measurement of the neutron polarization and S_3 can be used to calculate a constant K, such that $AP_3 = KS_3$, thus calibrating the ^{3}He NMR system. For the NPDGamma test run 2000, a supermirror was used as an analyzer to measure the neutron beam polarization. The direction of the ^{3}He polarization was reversed using an NMR AFP flip, and the supermirror transmission was measured for both ^{3}He spin states, ($F_\uparrow$ and $F_\downarrow$). The neutron beam polarization is then:

$$P_n = \left(\frac{F_\uparrow - F_\downarrow}{F_\uparrow + F_\downarrow}\right) R \tag{10}$$

where R is a correction to the neutron polarization due to the supermirror not having an infinite flipping ratio, ($R \approx 1 + 2/f$, where f is the supermirror flipping ratio). The supermirror has a useful range of approximately 2–10 meV, and was measured to have a flipping ratio of 33 on a 4.3 meV monochromatic neutron beam line at NIST.

$$AP_3 = KS_3 \tag{11}$$

$$K = 0.0397\frac{\text{amagat cm}}{\text{mV}} \tag{12}$$

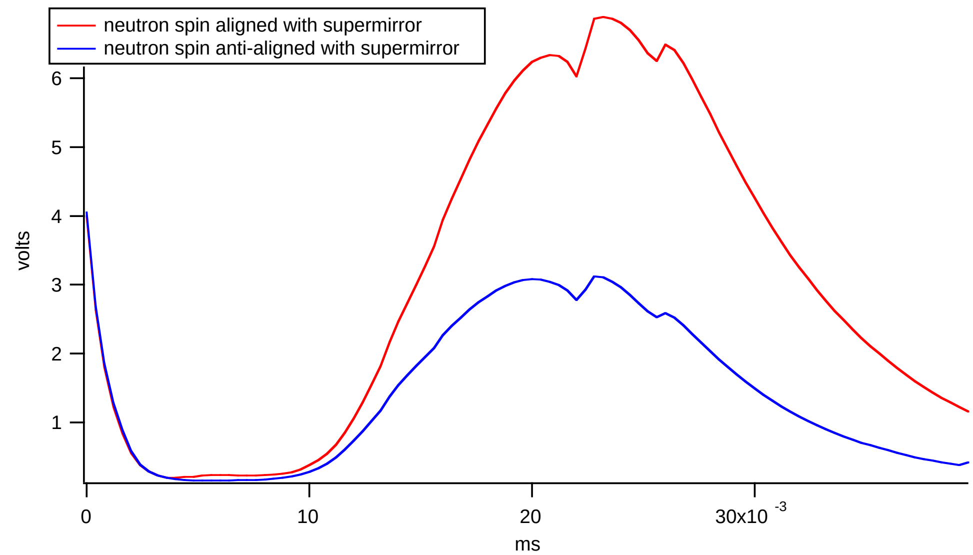

Figure 1: Supermirror transmission for the two spin states

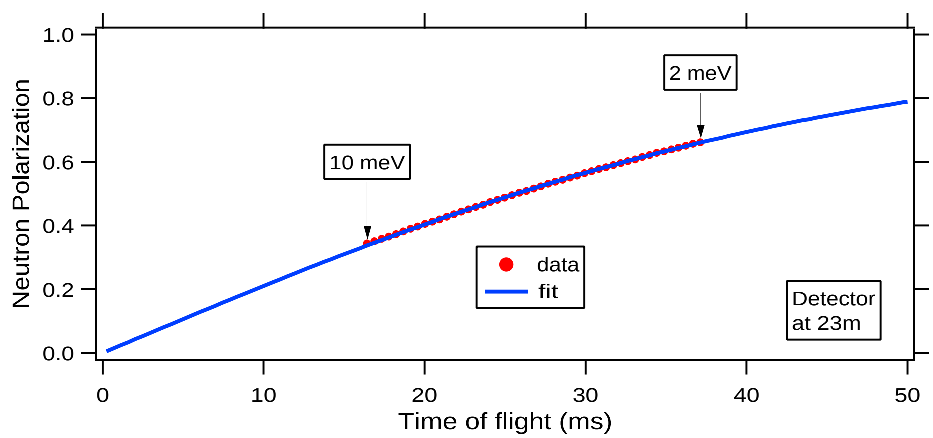

Figure 2: Neutron beam polarization as a function of time of flight

Target	Runs $\star$	NMR signal
Chlorine	3216 – 3220	37.95mV
	3293 – 3382	39.73mV
	3216 – 3382	39.64mV
Cadmium	3386 – 3403	40.21mV
	3494 – 3576	40.18mV
	3386 – 3576	40.19mV
Lanthanum	3589 – 3640	40.27mV
	3666 – 3739	40.05mV
	3589 – 3739	40.13mV

Table 1: NMR signal for each target and run block ($\star$ Not every run in a data block is a good asymmetry run)

The transmission of the supermirror as measured in the neutron back monitor is shown in figure 1 for the two ^{3}He spin states. The difference between the two signals is large and significantly above background between 2 meV and 10 meV. The neutron beam polarization between 2 meV and 10 meV calculated using the supermirror transmission and equation 10 is shown in figure 2. A single parameter fit to the data using equation 8 is also shown. The error in the value of K from a single fit is much less than 1%. The spread in the value of K from 4 different measurements of the neutron beam polarization using a ^{3}He spin flip is about 1%. A 10% error in the value of the flipping ratio would change the value of K by about 1%.

The ^{3}He NMR signal as a function of time during the asymmetry data collection is shown in figure 3. The data collection period for each of the three targets is shown at the bottom of the figure. For each target, the data collection was broken up into two blocks due to a period of no beam. For each block of data, the average NMR signal was calculated, and then for each target, the average NMR signal was calculated. A summary of the results is given in table 1. The error in the value of the NMR signal is about 1%, giving an overall error for the neutron beam polarization of 2%.

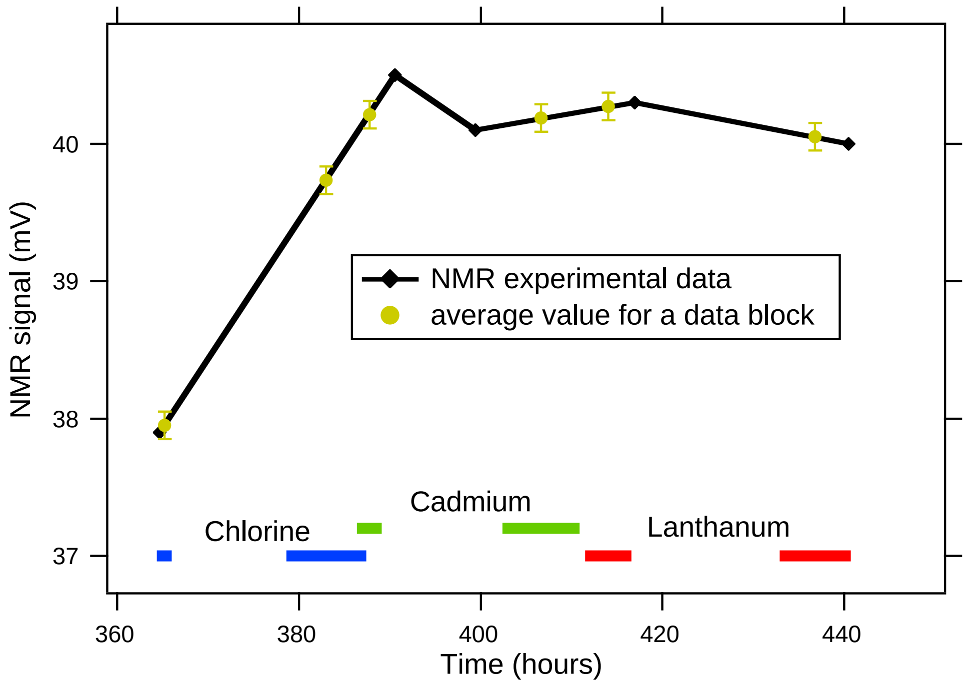

Figure 3: ^{3}He NMR signal during asymmetry data collection

For the NPDGamma test run 2000, the netron polarization and transmission are:

$$P_n = \tanh\left(0.0125 S_3(tof)/L\right) \tag{13}$$

$$T_n = e^{-\left(1.89(tof)/L\right)} \cosh\left(0.0125 S_3(tof)/L\right) \tag{14}$$

using $A = 6.0$ amagat cm, and where the ^{3}He NMR signal is found in table 1 and (tof) is in ms.

The density of the ^{3}He cell when filled was 3.27 amagats and it's length was 1.61 cm, giving it a thickness of 5.28 amagat cm when cold. When the pumping cell was heated to 175 degrees Celsius, the density in the hot pumping cell decreased while the density in the cold filter cell increased so that the pressure remained equalized. Under normal running conditions, the ^{3}He spin filter cell had a density times thickness of 6.0 amagat cm, which gives it a polarization of 26.5% when the NMR signal is 40mV.